Productive performance of brown-egg laying pullets from hatching to 5 weeks of age as affected by fiber inclusion, feed form, and energy concentration of the diet[1]

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ABSTRACT The effects of fiber inclusion, feed form, and energy concentration of the diet on the growth performance of pullets from hatching to 5 wk age were studied in 2 experiments. In Experiment 1, there was a control diet based on cereals and soybean meal, and 6 extra diets that included 2 or 4% of cereal straw, sugar beet pulp (SBP), or sunflower hulls (SFHs) at the expense (wt/wt) of the whole control diet. From hatching to 5 wk age fiber inclusion increased ($P < 0.05$) ADG and ADFI, and improved ($P < 0.05$) energy efficiency (EnE; kcal AME_n/g ADG), but body weight (BW) uniformity was not affected. Pullets fed SFH tended to have higher ADG than pullets fed SBP ($P = 0.072$) with pullets fed straw being intermediate. The feed conversion ratio (FCR) was better ($P < 0.05$) with 2% than with 4% fiber inclusion. In Experiment 2, 10 diets were arranged as a 2×5 factorial with 2 feed forms (mash vs. crumbles) and 5 levels of AME_n (2,850, 2,900, 2,950, 3,000, and 3,050 kcal/kg). Pullets fed crumbles were heavier and had better FCR than pullets fed mash ($P < 0.001$). An increase in the energy content of the crumble diets reduced ADFI and improved FCR linearly, but no effects were detected with the mash diets ($P < 0.01$ and $P < 0.05$ for the interactions). Feeding crumbles tended to improve BW uniformity at 5 wk age ($P = 0.077$) but no effects were detected with increases in energy concentration of the diet. In summary, the inclusion of moderate amounts of fiber in the diet improves pullet performance from hatching to 5 wk age. The response of pullets to increases in energy content of the diet depends on feed form with a decrease in feed intake when fed crumbles but no changes when fed mash. Feeding crumbles might be preferred to feeding mash in pullets from hatching to 5 wk age.

Key words: crumble feed, mash feed, straw, sugar beet pulp, sunflower hulls

INTRODUCTION

The inclusion of fibrous ingredients in poultry diets reduces feed intake (**FI**) (Kondra et al., 1974; Sklan et al., 2003) and nutrient digestibility (Rougière and Carré, 2010), and might affect the incidence of enteric disorders in poultry (Montagne et al., 2003; Shakouri et al., 2006; Mateos et al., 2012). Recent research conducted with young broilers, however, have shown that the inclusion of moderate amounts of insoluble fiber sources, such as oat hulls (**OHs**) and sunflower hulls (**SFHs**), in the diet stimulates the development and physiology of the gastrointestinal tract (**GIT**) (González-Alvarado et al., 2008; Svihus, 2011; Sacranie et al., 2012) and might improve broiler performance (Jiménez-Moreno et al., 2009b; González-Alvarado et al., 2010). However, the information available on the effects of including fiber sources differing in physico-chemical characteristics on growth performance of pullets is very limited.

Pelleting improves the ADG and feed conversion ratio (**FCR**) in broilers (Amerah et al., 2007; Serrano et al., 2012; Abdollahi et al., 2013) with most of the benefits associated to higher FI and reduced feed wastage (Serrano et al., 2013). However, the information available on the influence of feed form of the diet on productive performance in pullets is scarce (Frikha et al., 2009b). Probably pelleting of the feed might be of less benefit in pullets than in broilers because of the lower growth rate and reduced capacity for voluntary FI of pullets.

Energy concentration of the diet affects FI and growth performance in broilers (Brickett et al., 2007), pullets (Frikha et al., 2009a), and laying hens (Pérez-Bonilla et al., 2012). Birds eat to satisfy their energy requirements and therefore voluntary FI decreases as the energy content of the diet increases (Leeson et al., 1996; Veldkamp et al., 2005). High-energy diets contain usually more fat and are more palatable than low-energy diets which might favor energy intake (**EnI**) of the birds (Frikha et al., 2009a). Moreover, supplemental fat reduces the rate of feed passage and might improve the utilization of other components of the diet (Mateos and Sell, 1980, 1981). In contrast, if the diet is diluted excessively, birds might not consume enough feed to maintain EnI at a constant value, which may reduce productive performance (Nielsen, 2004; Pérez-Bonilla et al., 2012).

The hypothesis tested in this study was that the inclusion of moderate amounts of fiber in the diet could improve growth performance of young pullets. Also, it was hypothesized that feeding crumbles and increasing the energy content of the diet could improve ADG and FCR of the birds. The purpose of this study was to investigate in 2 experiments the effect of including 3 fiber sources with different physico-chemical characteristics, and of feed form and energy concentration of the diet on the growth performance of brown egg-laying pullets from hatching to 5 wk age.

MATERIALS AND METHODS

The experimental procedures described in this study were approved by the Animal Ethics Committee of the Universidad Politécnica de Madrid and were in compliance with the Spanish guidelines for the care and use of animals in research (Boletín Oficial Del Estado, 2007).

Experiment 1

Husbandry. In total, 3,500 1-day-old Lohmann Brown pullets (37.3 ± 1.27 g) were housed in an environmentally controlled barn. Pullets were weighed individually and randomly allotted in groups of 50 to 70 cages (40 x 80 x 68 cm; Facco, Padova, Italy) provided with an open-trough feeder and 2 low-pressure nipple drinkers. The average body weight (**BW**) of the pullets was similar for all cages. Pullets were beak-trimmed at the hatchery and kept on a 23 h/d light program for the first week of life. Then, the light was decreased 2 h/wk until reaching 15 h/d at the end of the trial. Barn temperature was maintained at 32 ± 1.5°C for the first 3 d of life, and was reduced gradually until reaching 21°C at the end of the trial. Because of the dimensions of the cage only 22 pullets chosen at random and remained in these cages after 21 d age. During the rearing period, the pullets were managed and vaccinated against main diseases (infectious bronchitis disease, Marek disease, infectious bursal disease, Newcastle disease, and *Salmonella* spp.) according to accepted commercial practices.

Ingredients, diets, and experimental design. The cereal straw and the sugar beet pulp (**SBP**) were received as 9 mm pellets, whereas the SFH was received in meal form. The straw used was a 80:20 mixture of wheat and barley straw, and was treated before pelleting with a 2% sodium hydroxide solution. Before being included in their respective experimental diets, all fiber sources were ground using a hammer mill provided with a 4 mm screen. The calculated and determined chemical analysis, geometric mean diameter (**GMD**), water-holding capacity (**WHC**, mL/g DM), swelling capacity (**SWC**, mL/g DM), and buffer properties of the fiber sources are shown in Table 1.

The control diet was based on corn, wheat, and soybean meal. The other 6 experimental diets resulted from the inclusion of 2 or 4% straw, SBP, or SFH at the expense (wt/wt) of the whole control diet. All diets met or exceeded the nutrient requirements of pullets as recommended by the Fundación Española Desarrollo Nutrición Animal (2008) but feeds that included a fiber source had more dietary fiber, and slightly less AME_n and CP, than the control feed. All diets contained a commercial enzyme complex with xylanase and β-glucanase activities (Roxazyme, DSM S.A., Madrid, Spain). In the formulation of the diets it was accepted that the inclusion of the enzyme complex increased the energy content of the wheat by 2% (from 3,150 to 3,213 kcal AME_n/kg) but had no effects on the energy content of the corn (Fundación Española Desarrollo Nutrición Animal, 2010). Diets were offered for ad libitum consumption in mash form. New feed was added into the feeders 2×/day (7.00 am and 4.00 pm) to reduce feed spillage. The ingredient composition and the calculated and determined chemical analysis of the diets are shown in Table 2 and their particle size distribution and GMD are shown in Table 3.

The experimental design was completely randomized with 7 treatments that consisted of a control diet without any additional fiber and 6 additional diets that formed a 3×2 factorial, with 3 fiber sources (straw, SBP, and SFH) and 2 levels of inclusion (2 and 4%). Each treatment was replicated 10 times and the experimental unit was the cage for all measurements.

Measurements. Feed disappearance and BW were determined by cage at week intervals and mortality was recorded and weighed as produced. Feed wastage was not measured. From these data, ADG, ADFI, and FCR were determined by week and for the entire experimental period. In addition, EnI expressed as kcal of AME_n consumed per day and energy efficiency (**EnE**), expressed as kcal of calculated AME_n per g of ADG, were also estimated for the entire experimental period. At the end of the experiment (5 wk age) the pullets were weighed individually and BW uniformity was determined by replicate as indicated by Peak et al. (2000). Briefly, the CV of the individual BW of the pullets of each cage was generated and this variable was used as an indirect measurement of BW uniformity of the birds.

Statistical analysis. Data on growth performance and BW uniformity were analyzed as a completely randomized design with 7 treatments using the GLM procedure of SAS Institute (1990). Pre-planned polynomial contrasts were performed as indicated by García et al. (2008), taking into account that 6 of the diets formed a 3 × 2 factorial. The model studied the effects of 1) control diet vs. the average of the 6 diets that contained a fiber source, 2) main effect of the fiber source,

Table 1. Calculated and determined analysis (% as fed basis, unless otherwise indicated), and physico-chemical characteristics of the fiber sources, Experiment 1.

Fiber source	Straw	Sunflower hulls	Sugarbeet pulp
Calculated analysis[1]			
AME_n (kcal/kg)	200	340	900
Ether extract	1.6	3.0	0.8
Crude fiber	36.0	48.7	18.2
Neutral detergent fiber	72.0	72.2	42.8
Crude protein	3.7	5.7	9.2
Arg	-	0.46	0.42
Ile	-	-	0.35
Lys	-	0.17	0.54
Met	-	0.10	0.16
Met + Cys	-	0.17	0.28
Thr	-	0.18	0.44
Trp	-	0.05	0.09
Val	-	0.27	0.55
Determined analyses			
DM	91.3	90.1	92.0
Gross energy (kcal/kg)	3,854	4,201	3,729
CP	2.8	5.9	9.2
Total ash	6.7	4.3	5.6
Neutral detergent fiber	69.9	58.2	31.7
Acid detergent fiber	41.5	40.5	15.6
Acid detergent lignin	5.6	13.1	1.7
Total dietary fiber	78.5	84.0	64.7
Soluble dietary fiber	3.8	3.0	10.6
Insoluble dietary fiber	74.7	81.0	54.1
Physical properties			
Particle size[2]			
2,500	0.2	0.8	1.2
1,250	12.3	8.7	33.5
630	40.4	55.7	35.2
315	28.4	24.6	18.4
160	15.3	9.9	9.0
80	2.9	0.3	2.3
GMD[3] ± GSD[4]	602 ± 2.01	701 ± 1.75	835 ± 2.12
WHC[5] ± SD	7.5 ± 0.14	6.6 ± 0.06	8.7 ± 0.27
SWC[6] ± SD	3.6 ± 0.23	3.3 ± 0.25	6.6± 0.56
Buffer properties			
Initial pH[7]	8.39 ± 0.052	5.64 ± 0.023	5.62 ± 0.033
Base-buffering capacity[8]	-	80.7 ± 6.4	50.9 ± 5.6
Acid-buffering capacity[9]	134.2 ± 10.2	124.1 ± 16.7	96.3 ± 5.2

[1]According to Fundación Española para el Desarrollo de la Nutrición Animal (2010).

[2]Measured after grinding with a hammer mill provided with a 4 mm screen. Percentage of particles bigger than 2,500 μm or smaller than 80 μm were negligible for all diets.

[3]Geometric mean diameter (μm).

[4]GSD = Log normal SD.

[5]Water holding capacity (mL/g DM).

[6]Swelling capacity (mL/g DM).

[7]pH of 10 g DM of the fiber source suspended in 200 mL double-distilled water.

[8]μequiv NaOH required to increase the pH of 10 g DM of the fiber source suspended in 200 mL double-distilled water from the initial pH to pH 7 divided by pH change. Base-buffering capacity of the straw could not be measured because the initial pH was above 7.00.

[9]μequiv HCl required to decrease the pH of 10 g DM of the fiber source suspended in 200 mL double-distilled water from pH 7 to pH 4 divided by pH change.

3) main effect of level of fiber source, and 4) the interaction between source and level of inclusion of the fiber source. Differences among treatment means were considered significant at $P < 0.05$. When a significant difference was detected, means were separated using the Tukey test. Results in the tables are presented as means.

Experiment 2

Husbandry. In total, 3,000 brown-egg laying pullets (36.7 ± 2.91 g) were used in Experiment 2. The experimental procedures, including type and age of the birds, management, growth performance controls, and duration of the trial were similar to those indicated for Experiment 1.

Diets and experimental design. Five diets differing in AME_n content (2,850, 2,900, 2,950, 3,000, and 3,050 kcal AME_n/kg) were used. The 2 extreme diets (2,850 and 3,050 kcal/kg) were formulated to have similar indispensable amino acids (**AAs**) and nutrient content per unit of energy (Fundación Española Desarrollo Nutrición Animal, 2008). The intermediate feeds (2,900, 2,950, and 3,000 kcal AME_n/kg) were obtained by

Table 2. Ingredient composition and nutrient content (% as fed basis, unless otherwise indicated) of the experimental diets, Experiment 1.

	Control	Straw 2%	Straw 4%	Sunflower hulls 2%	Sunflower hulls 4%	Sugarbeet pulp 2%	Sugarbeet pulp 4%
Ingredient							
Corn	38.0	37.2	36.5	37.2	36.5	37.2	36.5
Wheat, 11.2% CP	20.0	19.6	19.2	19.6	19.2	19.6	19.2
Soybean meal, 47% CP	35.0	34.3	33.6	34.3	33.6	34.3	33.6
Straw	-	2.0	4.0	-	-	-	-
Sunflower hulls	-	-	-	2.0	4.0	-	-
Sugarbeet pulp	-	-	-	-	-	2.0	4.0
Poultry fat	2.7	2.6	2.5	2.6	2.5	2.6	2.5
Dicalcium phosphate	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Calcium carbonate	1.26	1.27	1.18	1.27	1.18	1.27	1.18
Sodium chloride	0.36	0.35	0.35	0.35	0.35	0.35	0.35
DL-Met, 99%	0.18	0.18	0.17	0.18	0.17	0.18	0.17
Vitamin and mineral premix[1]	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Calculated analysis[2]							
AME_n (kcal/kg)	2,956	2,900	2,843	2,904	2,852	2,915	2,874
Ether extract	5.0	5.0	4.9	5.0	5.0	5.0	4.9
Crude fiber	2.8	3.5	4.2	3.7	4.7	3.2	3.5
Neutral detergent fiber	8.3	9.6	10.8	9.6	10.9	9.0	9.8
Crude protein	21.5	21.1	20.7	21.1	20.8	21.2	21.0
Digestible amino acids							
Arg	1.30	1.28	1.25	1.28	1.25	1.28	1.25
Lys	1.01	0.99	0.97	0.99	0.97	0.99	0.97
Met	0.47	0.46	0.45	0.46	0.45	0.46	0.45
Met + Cys	0.77	0.76	0.74	0.76	0.74	0.76	0.74
Thr	0.69	0.68	0.66	0.68	0.66	0.68	0.66
Trp	0.23	0.23	0.22	0.23	0.22	0.23	0.22
Calcium	0.97	0.96	0.95	0.96	0.95	0.97	0.97
Total phosphorus	0.84	0.83	0.81	0.83	0.82	0.83	0.81
Digestible phosphorus	0.53	0.52	0.51	0.52	0.51	0.52	0.51
Determined analyses							
DM	90.4	90.9	91.4	91.8	90.9	91.1	91.8
Gross energy (kcal/kg)	4,017	4,085	4,048	4,082	4,056	4,094	4,109
Crude fiber	2.9	3.5	4.2	3.3	4.7	2.9	3.1
Neutral detergent fiber	8.9	10.3	11.4	9.3	11.2	9.3	10.0
Acid detergent fiber	3.3	4.0	4.7	3.5	4.7	3.4	3.5
Acid detergent lignin	0.3	0.4	0.5	0.6	0.8	0.3	0.3
CP	20.8	20.2	21.1	21.5	20.1	21.1	20.9
Arg	1.44	1.37	1.36	1.37	1.35	1.36	1.40
Lys	1.12	1.13	1.10	1.10	1.08	1.11	1.08
Met	0.52	0.49	0.46	0.48	0.46	0.47	0.47
Met + Cys	0.85	0.85	0.81	0.82	0.82	0.83	0.81
Thr	0.81	0.81	0.78	0.77	0.78	0.76	0.76
Trp	0.27	0.25	0.26	0.26	0.24	0.27	0.24
Ash	1.03	7.1	7.5	7.2	6.8	7.3	6.8

[1]Provided the following (per kg of diet): vitamin A (trans-retinyl acetate), 10,000 IU; vitamin D_3 (cholecalciferol), 3,000 IU; vitamin E (all-*rac*-tocopherol-acetate), 30 mg; vitamin B_1, 2 mg; vitamin B_2, 8 mg; vitamin B_6, 4 mg; vitamin B_{12} (cyanocobalamin), 0.025 mg; vitamin K_3 (bisulphatemenadione complex), 3mg; choline (choline chloride), 250 mg; nicotinic acid, 60 mg; pantothenic acid (D-calcium pantothenate), 15 mg; folic acid, 1.5 mg; betaíne anhydrous, 80 mg; D-biotin, 0.15 mg; zinc (ZnO), 80 mg; manganese (MnO), 70 mg iron ($FeCO_3$), 60 mg; copper ($CuSO_4 \cdot 5H_2O$), 8 mg; iodine (KI), 2 mg; selenium (Na_2SeO_3), 0.2 mg; Roxazyme, 200 mg [1,600 U endo-1,4-β-glucanase (EC 3.2.1.4), 3,600 U endo-1,3 (4)-β-glucanase (EC 3.2.1.6), and 5,200 U endo-1,4-β-xylanase (EC 3.2.1.8)] supplied by DSM S.A., Madrid, Spain; and Natuphos 5000, 60 mg (300 Phytase units (FTU)/kg) supplied by Basf Espanola S.A., Tarragona, Spain.

[2]According to Fundación Española Desarrollo Nutrición Animal (2010).

judicious mixing in adequate proportions of the 2 summit diets. The batches of each of the 5 experimental diets were divided into 2 portions; the first portion was used as such and the second portion was steam-conditioned at 72°C for 60 s, passed through a pellet press (Model PVR 180 2T, Mabrik, Barcelona, Spain) provided with a 60 mm thick and a 3 mm screen die, and crumbled. The ingredient composition and the calculated and the determined chemical analysis of the diets are shown in Table 4. The particle size distribution and GMD of the diets are shown in Table 5. The experiment was completely randomized with 10 treatments in a factorial arrangement with 5 energy levels (2,850, 2,900, 2,950, 3,000, 3,050 kcal AME_n/kg) and 2 feed forms (crumble vs. mash). Each treatment was replicated 6 times and the experimental unit was the cage for all measurements.

Measurements. The same variables studied in Experiment 1 were measured in Experiment 2. The only difference was that in the present experiment, pullet

Table 3. Particle size distribution and geometric mean diameter (μm) of the experimental diets, Experiment 1.

		Straw		Sunflower hulls		Sugarbeet pulp	
	Control[1]	2%	4%	2%	4%	2%	4%
Particle size distribution[2]							
> 2,500	7.6	4.4	3.8	2.4	3.8	3.3	2.8
1,250	40.6	42.4	38.2	31.6	38.2	37.2	31.4
630	31.5	33.3	35.8	39.7	35.8	36.7	39.5
315	12.4	12.4	14.6	17.4	14.6	14.9	17.0
160	7.6	7.4	7.4	8.6	7.4	6.8	9.1
GMD ± GSD[3]	1,080 ± 2.03	1,050 ± 1.97	995 ± 1.96	902 ± 1.94	996 ± 1.95	991 ± 1.93	899 ± 1.96

[1]Water holding capacity (± SD) and the swelling capacity (± SD) of the control diet, measured in triplicate, were 2.1 ± 0.17 and 2.8 ± 0.30, respectively.

[2]Percentage of particles smaller than 160 μm or bigger than 2,500 μm was negligible for all diets.

[3]GSD = Log normal SD.

uniformity was determined at weekly intervals whereas in Experiment 1, uniformity was determined only at 5 wk age.

Statistical analysis. Data on growth performance and BW uniformity were analyzed as a completely randomized design with 10 treatments arranged as a 2 × 5 factorial using the GLM procedure of SAS Institute (1990). The model included feed form and energy concentration of the diets as main effects and their interactions. Treatment sums of squares for the effects of AME_n content of the diets on the different variables studied were partitioned into linear (**L**) and quadratic (**Q**) effects. Differences among treatment means were considered significant at $P < 0.05$. Significant differences between treatment means were separated using the Tukey test. Results in the tables are presented as means.

Laboratory Analysis

Representative samples of the fiber sources used in Experiment 1 and of the diets of Experiments 1 and 2 were ground in a laboratory mill (Retsch Model Z-I, Stuttgart, Germany) equipped with a 1 mm screen and analyzed for moisture by the oven-drying method (930.15), total ash by a muffle furnace method (942.05), and nitrogen by the Dumas method (968.06) using a Leco analyzer (Model FP-528, Leco Corp., St. Joseph, MI) as indicated by AOAC International (2005). The AA content of the diets was determined by ion-exchange chromatography (Hewlett-Packard 1100, Waldbronn, Germany) after acid hydrolysis, as indicated by De Coca-Sinova et al. (2008). Crude fiber (**CF**) content of the diets used in both experiments and ether extract of the diets used in Experiment 2 were determined as specified by Pérez-Bonilla et al. (2011). Gross energy (**GE**) of the fiber sources and diets was determined using an adiabatic bomb calorimeter (Model 1356, Parr Instrument Company, Moline, IL). Neutral detergent fiber (**NDF**), acid detergent fiber (**ADF**), and acid detergent lignin (**ADL**) of the fiber sources and diets from Experiment 1 were determined as described by Van Soest et al. (1991) and expressed on an ash-free basis. Also, dietary fiber (**DF**) (Method 985.29) and the insoluble fraction of DF (Method 991.43) of the fiber sources were analyzed as proposed by AOAC International (2005). The soluble fraction of DF was calculated by difference between total and insoluble DF. The WHC, SWC, and buffer properties of the fiber sources were determined as indicated by Jiménez-Moreno et al. (2009a). The mean particle size of the fiber sources and diets, expressed as GMD, was determined in 100 g samples using a Retsch shaker (Retsch, Stuttgart, Germany) provided with 8 sieves ranging in mesh from 5,000 to 40 μm, as described by the ASAE (1995). All the analyses were conducted in duplicate except for buffer properties and GMD determination that were conducted in triplicate.

RESULTS

Experiment 1

The straw, SFH, and SBP contained by analyses 2.8, 5.9, and 9.2 % CP, and 69.9, 58.2, and 31.7% NDF, respectively (Table 1). The GMD was 602, 701, and 835 μm for straw, SFH, and SBP, respectively. The determined nutrient content of the experimental diets, including the AA composition, was close to expected values, confirming that the ingredients were mixed correctly (Table 3). As the level of fiber increased, the GMD of the diet decreased (1,080, 981, and 963 μm for the control diet and for the average of the diets that contained 2 or 4% of the fiber sources, respectively).

Mortality was 2.9% and was not related to treatment (data not shown). Most of the mortality (2.6%) occurred during the first week of life. For the entire experimental period (from hatching to 5 wk age), the inclusion of fiber in substitution of the whole diet increased ($P < 0.05$) ADFI and ADG (Table 6), and improved ($P < 0.05$) EnE (Table 7). Most of the benefits of fiber inclusion were observed after the first week of life. In fact, pullets fed the fiber containing diets showed, as an average, higher ADG than pullets fed the control diet for the second (6.3 vs. 5.8 g/d; $P < 0.001$), third (8.9

Table 4. Ingredient composition and nutrient content (% as fed basis, unless otherwise indicated) of the experimental diets, Experiment 2.

AME_n, kcal/kg	2,850	2,900	2,950	3,000	3,050
Ingredient					
Corn	35.0	35.0	35.0	35.0	35.0
Wheat, 11.2% CP	19.1	18.2	17.4	16. 5	15.6
Soybean meal, 45.5% CP	33.1	34.8	36.5	38.2	39.9
Sunflower meal, 28% CP	6.0	4.5	3.0	1.5	-
Soy oil	2.7	3.4	4.1	4.7	5.4
Dicalcium phosphate	2.07	2.07	2.07	2.06	2.06
Calcium carbonate	1.05	1.05	1.05	1.04	1.04
Sodium chloride	0.35	0.35	0.35	0.35	0.35
DL-methionine, 99%	0.13	0.14	0.14	0.15	0.15
Vitamin and mineral premix[1]	0.50	0.50	0.50	0.50	0.50
Calculated analyses[2]					
AME_n (kcal/kg)	2,850	2,900	2,950	3,000	3,050
Ether extract	5.1	5.8	6.4	7.1	7.7
Crude fiber	4.5	4.2	3.9	3.6	3.3
Neutral detergent fiber	11.1	10.6	10.0	9.5	8.9
CP	21.7	22.0	22.2	22.5	22.7
Digestible amino acids					
Arg	1.32	1.34	1.35	1.37	1.38
Lys	0.97	1.00	1.02	1.05	1.08
Met	0.43	0.44	0.44	0.45	0.46
Met + Cys	0.72	0.73	0.74	0.75	0.76
Thr	0.68	0.70	0.71	0.72	0.73
Trp	0.23	0.23	0.23	0.24	0.24
Calcium	1.10	1.10	1.10	1.10	1.10
Total phosphorus	0.82	0.82	0.81	0.81	0.80
Digestible phosphorus	0.44	0.44	0.44	0.43	0.43
Determined analysis[3]					
DM	93.3	91.3	92.2	91.8	92.6
Gross energy (kcal/kg)	4,134	4,145	4,192	4,212	4,279
Ether extract	5.0	6.2	6.5	7.0	7.3
Crude fiber	4.4	4.2	3.9	3.8	3.5
CP	21.1	22.2	21.9	22.2	23.5
Arg	1.42	1.50	1.48	1.50	1.52
Lys	1.11	1.15	1.16	1.22	1.25
Met	0.49	0.50	0.51	0.49	0.48
Met + Cys	0.84	0.84	0.86	0.85	0.87
Thr	0.80	0.84	0.84	0.85	0.85
Ash	6.0	7.5	7.6	6.1	6.1

[1]Provided the following (per kg of diet): vitamin A (trans-retinyl acetate), 10,000 IU; vitamin D_3 (cholecalciferol), 3,000 IU; vitamin E (all-*rac*-tocopherol-acetate), 30 mg; vitamin B_1, 2 mg; vitamin B_2, 8 mg; vitamin B_6, 4 mg; vitamin B_{12} (cyanocobalamin), 0.025 mg; vitamin K_3 (bisulphatemenadione complex), 3mg; choline (choline chloride), 250 mg; nicotinic acid, 60 mg; pantothenic acid (D-calcium pantothenate), 15 mg; folic acid, 1.5 mg; betaíne anhydrous, 80 mg; D-biotin, 0.15 mg; zinc (ZnO), 80 mg; manganese (MnO), 70 mg iron ($FeCO_3$), 60 mg; copper ($CuSO_4{\cdot}5H_2O$), 8 mg; iodine (KI), 2 mg; selenium (Na_2SeO_3), 0.2 mg; Roxazyme, 200 mg [1,600 U endo-1,4-β-glucanase (EC 3.2.1.4), 3,600 U endo-1,3 (4)-β-glucanase (EC 3.2.1.6), and 5,200 U of endo-1,4-β-xylanase (EC 3.2.1.8)] supplied by DSM S.A., Madrid, Spain; and Natuphos 5000, 60 mg (300 FTU/kg) supplied by Basf Espanola S.A., Tarragona, Spain.

[2]According to Fundación Española Desarrollo Nutrición Animal (2010).

[3]Data presented correspond to the average of the mash and crumble feeds, except for amino acids for which only the mash diets were analyzed.

vs. 8.5 g/d; $P < 0.01$), and fourth week (10.8 vs. 10.1 g/d; $P < 0.01$) age.

From hatching to 5 wk age, pullets fed the SFH containing diets tended to have higher ($P = 0.072$) ADG than pullets fed the SBP containing diets, with pullets fed the straw containing diets being intermediate. However, ADFI, FCR, and EnE were not affected by type of fiber. Similarly, an increase in the level of inclusion

Table 5. Particle size distribution and geometric mean diameter (μm) of the experimental diets, Experiment 2.

AME_n, kcal/kg	32,850		2,900		2,950		3,000		3,050	
	Mash	Crumbles	Mash	Crumbles	Mash	Crumbles	Mash	Crumbles	Mash	Crumbles
Particle size[1]										
> 2500	12.1	8.8	10.2	10.1	12.2	7.1	11.8	4.6	9.8	4.7
1,250	27.2	66.1	29.6	56.6	28.1	54.2	27.2	50.6	26.8	52.3
630	32.1	18.6	32.8	21.7	33.4	25.0	34.3	28.7	35.0	27.7
315	18.0	4.6	17.1	8.3	17.0	9.6	17.5	11.2	18.3	10.4
160	10.5	18.0	10	3.1	9.2	3.9	9.2	4.5	10.1	4.6
GMD ± GSD[2]	968 ± 2.22	1,491 ± 1.69	986 ± 2.18	1,384 ± 1.86	1,000 ± 2.18	1,272 ± 1.89	968 ± 2.17	1,158 ± 1.90	940 ± 2.15	1,144 ± 1.90

[1]Percentage of particles smaller than 160 μm or bigger than 2,500 μm was negligible for all diets.

[2]GSD = Log normal SD.

Table 6. Influence of fiber source and level of fiber inclusion in the diet on growth performance of pullets from hatching to 5 wk age, Experiment 1.

	0 to 1 wk			1 to 2 wk			2 to 3 wk			3 to 4 wk			4 to 5 wk			0 to 5 wk		
	ADFI (g)	ADG (g)	FCR[1]	ADFI (g)	ADG (g)	FCR	ADFI (g)	ADG (g)	FCR	ADFI (g)	ADG(g)	FCR	ADFI (g)	ADG (g)	FCR	ADFI (g)	ADG (g)	FCR
Fiber inclusion																		
Control	8.17	4.57	1.79	12.9[b]	5.83[b]	2.21	19.6[b]	8.51[b]	2.30	24.8	10.1[b]	2.46	30.7	11.6	2.66	19.2[b]	8.11[b]	2.37
Fiber	8.81	4.71	1.87	13.9[a]	6.30[a]	2.20	20.4[a]	8.91[a]	2.29	25.6	10.8[a]	2.37	30.9	11.4	2.70	19.9[a]	8.44[a]	2.36
Fiber source																		
Straw	8.77	4.75	1.85	13.8	6.26[b]	2.21	20.4	8.97	2.27	25.5	10.8	2.37	30.9	11.5	2.69	19.9	8.42	2.36
SFH[2]	8.92	4.77	1.87	14.1	6.49[a]	2.17	20.4	8.95	2.28	25.8	11.0	2.36	30.9	11.6	2.66	20.0	8.56	2.34
SBP[3]	8.74	4.62	1.89	13.8	6.24[b]	2.20	20.4	8.80	2.31	25.6	10.7	2.39	30.8	11.2	2.74	19.9	8.32	2.39
Inclusion level (%)																		
2	8.84	4.74	1.87	13.9	6.37	2.18	20.2	8.93	2.26[b]	25.6	10.9	2.34	30.6	11.5	2.66	19.8	8.49	2.34[b]
4	8.78	4.69	1.87	13.9	6.28	2.21	20.6	8.88	2.31[a]	25.7	10.7	2.41	31.1	11.4	2.73	20.0	8.38	2.39[a]
Standard deviation[4]	1.030	0.490	0.229	0.58	0.660	0.105	0.72	0.408	0.089	1.85	0.64	0.175	1.47	0.90	0.216	0.75	0.320	0.092
									Probability									
Control vs. fiber diets[5]	0.074	0.426	0.327	<0.001	<0.001	0.646	0.002	0.006	0.606	0.185	0.001	0.062	0.803	0.662	0.594	0.010	0.004	0.632
Fiber source	0.859	0.625	0.806	0.164	0.023	0.121	0.977	0.371	0.347	0.829	0.473	0.844	0.952	0.330	0.417	0.713	0.072	0.284
Inclusion level	0.813	0.603	0.749	0.723	0.726	0.990	0.089	0.639	0.035	0.697	0.142	0.121	0.262	0.571	0.199	0.392	0.218	0.047
Fiber source x inclusion level	0.812	0.738	0.986	0.982	0.648	0.549	0.879	0.643	0.339	0.838	0.611	0.975	0.922	0.878	0.945	0.884	0.528	0.675

[a–b]Within a column, means without a common superscript differ ($P < 0.05$).
[1]Feed conversion ratio.
[2]Sunflower hulls.
[3]Sugar beet pulp.
[4]Standard deviation: n = 20 for fiber source and n = 30 for level of inclusion of fiber.
[5]Control without additional fiber vs. average of the 6 diets containing a fiber source.

Table 7. Influence of fiber source and level of fiber inclusion in the diet on energy intake[1] (kcal AME_n/d) and energy efficiency (kcal AME_n/g ADG) of the pullets from hatching to 5 wk age, Experiment 1.

	0 to 5 wk	
	EnI	EnE
Fiber inclusion		
Control	56.9	7.03[a]
Fiber	57.4	6.81[b]
Fiber source		
Straw	57.0	6.78
Sunflower hulls	57.6	6.73
Sugar beet pulp	57.5	6.91
Inclusion level (%)		
2	57.6	6.80
4	57.1	6.82
Standard deviation[2]	2.17	0.267
Probability		
Control vs. fiber diets[3]	0.480	0.020
Fiber source	0.661	0.107
Inclusion level	0.357	0.743
Fiber source × inclusion level	0.850	0.548

[a-b]Within a column, means without a common superscript differ ($P < 0.05$).
[1]Calculated energy intake (kcal AME_n/d). Calculated AME_n values are presented in Table 2.
[2]Standard deviation: n = 20 replicates for fiber source and n = 30 replicates for level of inclusion of fiber.
[3]Control without additional fiber vs. average of the 6 diets containing fiber source.

of fiber from 2 to 4% affected neither ADFI, ADG, nor EnE, but hindered ($P < 0.05$) FCR. Body weight uniformity at 5 wk age was not affected by the inclusion of fiber in the diet (Table 8).

Experiment 2

The determined nutrient content of the experimental diets were close to expected values and similar for the mash as for their corresponding crumble diets, confirming that the ingredients were mixed correctly (Table 4). The GMD of the 2,850, 2,900, 2,950, 3,000, and 3,050 kcal AME_n/kg diets was 968, 986, 1,000, 968, and 940 μm for the mash diets, and 1,491, 1,384, 1,272, 1,158, and 1,144 μm for the crumble diets, respectively. Mortality was 2.7% and was not related to treatment (data not shown). Most of the mortality (2.6%) occurred during the first week of life.

Feed form. From hatching to 5 wk age, pullets fed crumbles had lower ADFI (21.1 vs. 21.5 g/d; $P < 0.01$), greater ADG (9.8 vs. 9.2 g/d; $P < 0.001$), and better FCR (2.14 vs. 2.33; $P < 0.001$) than pullets fed mash (Table 9). Consequently, EnE (6.32 vs. 6.87 kcal/AME_n/g ADG; $P < 0.001$) was improved when the diets were crumbled (Table 10). The beneficial effects of crumbling on ADG and FCR were observed at all ages. Average daily FI, however, was higher ($P < 0.05$) in pullets fed crumbles than in pullets fed mash for the first week of life, but an opposite effect was observed after this age.

Table 8. Influence of fiber source and level of fiber inclusion in the diet on BW uniformity[1] of pullets at 5 wk age, Experiment 1.

	CV, %
Fiber inclusion	
Control	8.12
Fiber	8.75
Fiber source	
Straw	9.21
Sunflower hulls	8.43
Sugar beet pulp	8.63
Inclusion level (%)	
2	8.61
4	8.90
Standard deviation[2]	1.467
Probability	
Control vs. fiber diets[3]	0.209
Fiber source	0.225
Inclusion level	0.456
Fiber source × inclusion level	0.815

[1]Evaluated as the CV (%) of BW (Peak et al., 2000).

[2]Standard deviation: n = 20 for fiber source and n = 30 for level of inclusion of fiber.

[3]Control without any additional fiber vs. the average of the 6 diets containing a fiber source.

Crumbling tended to improve BW uniformity of the pullets at all ages, with differences being significant at 3 wk (8.8 vs. 10.2%; $P < 0.05$) and 4 wk (8.0 vs. 8.5%; $P < 0.05$) age (Table 11).

Energy concentration. Pullet performance was affected in different ways by energy concentration of the diet. From hatching to 5 wk age, an increase in the energy concentration of the diet decreased ADFI and improved FCR when the feeds were fed in crumble form, but no differences were detected when fed in mash form ($P < 0.01$ and $P < 0.05$ for the interaction, respectively) (Figure 1). Consequently, EnI was similar for all pullets fed crumbles, irrespective of the energy concentration of the diet, but increased in pullets fed mash as the AME_n increased ($P < 0.01$ for the interaction). The interactions between feed form and energy concentration of the diet were more evident during the last part of the experiment. BW uniformity was not affected by the energy content of the diet at any age (Table 11).

DISCUSSION

Experiment 1

The inclusion of additional fiber in the diet increased FI by 3.6% as an average and improved ADG by 4.1% from hatching to 5 wk age; consequently, FCR was not affected. The authors have not found any research on the effects of dietary fiber on growth performance of pullets to compare with the results reported in this paper. In broilers, Jiménez-Moreno et al. (2009b) observed that the inclusion of 3% OH in the diet from 1 to 21 d age improved FCR by 5.5% and ADG by 6.1%

Table 9. Influence of feed form and energy content (AME_n, kcal/kg) of the diet on growth performance of the pullets from hatching to 5 wk age, Experiment 2.

Feed form	AME_n (kcal/kg)	0 to 1 wk			1 to 2 wk			2 to 3 wk			3 to 4 wk			4 to 5 wk			0 to 5 wk		
		ADFI (g)	ADG (g)	FCR[1]	ADFI (g)	ADG (g)	FCR	ADFI (g)	ADG (g)	FCR	ADFI (g)	ADG (g)	FCR	ADFI (g)	ADG (g)	FCR	ADFI (g)	ADG (g)	FCR
Mash	2,850	8.8[ab]	5.1	1.73	13.9	6.6	2.11	21.0	9.8	2.16	30.0[abc]	12.0	2.51	32.3[ab]	12.1	2.68	21.2[ab]	9.1	2.33[ab]
	2,900	8.8[ab]	5.3	1.67	14.1	6.8	2.07	21.2	10.1	2.10	30.6[abc]	12.5	2.45	33.2[ab]	11.7	2.84	21.5[ab]	9.3	2.32[ab]
	2,950	8.9[ab]	5.1	1.76	14.0	6.6	2.12	20.9	9.6	2.18	31.6[a]	12.6	2.50	33.3[ab]	11.7	2.85	21.7[a]	9.1	2.38[a]
	3,000	9.0[ab]	5.2	1.75	13.6	6.5	2.09	21.0	10.3	2.04	30.5[abc]	12.6	2.43	33.7[ab]	12.1	2.78	21.6[ab]	9.3	2.31[ab]
	3,050	8.4[ab]	5.1	1.64	13.3	6.6	2.02	22.2	10.4	2.14	30.9[ab]	12.5	2.49	32.9[ab]	12.3	2.69	21.5[ab]	9.4	2.30[abc]
Crumbles	2,850	9.4[a]	5.6	1.68	13.9	6.9	2.01	20.9	10.1	2.06	30.0[abc]	13.2	2.27	34.4[a]	13.0	2.67	21.7[a]	9.8	2.22[bcd]
	2,900	9.4[a]	5.7	1.64	13.2	6.7	1.97	22.0	10.6	2.07	28.9[abc]	13.1	2.21	33.3[ab]	13.2	2.53	21.4[ab]	9.9	2.16[cde]
	2,950	9.4[a]	5.7	1.65	13.1	6.8	1.95	21.3	10.2	2.08	29.1[abc]	13.1	2.23	32.7[ab]	12.8	2.56	21.1[ab]	9.7	2.17[cde]
	3,000	9.1[ab]	5.5	1.65	13.2	7.0	1.87	21.1	10.4	2.03	28.2[bc]	13.3	2.12	32.3[ab]	13.1	2.46	20.8[ab]	9.9	2.10[de]
	3,050	8.2[b]	5.5	1.48	13.1	6.9	1.90	20.9	11.1	1.88	27.9[c]	12.8	2.18	32.2[b]	13.3	2.43	20.4[b]	9.9	2.06[e]
Sd[2]		0.57	0.32	0.107	0.98	0.36	0.142	1.69	0.92	0.230	1.46	0.75	0.120	1.11	0.86	0.168	0.59	0.32	0.071
										Probability									
Feed form		0.042	<.001	0.001	0.045	0.015	<.001	0.945	0.049	0.114	<.001	<.001	<.001	0.889	<.001	<.001	0.007	<.001	<.001
AME_n																			
Linear		0.002	0.356	0.022	0.063	0.781	0.067	0.690	0.062	0.265	0.244	0.717	0.138	0.078	0.400	0.063	0.026	0.137	<.001
Quadratic		0.015	0.722	0.037	0.988	0.749	0.808	0.927	0.408	0.665	0.493	0.201	0.400	0.729	0.249	0.176	0.337	0.829	0.230
Feed form × AME_n		0.032	0.633	0.114	0.926	0.4338	0.588	0.339	0.897	0.549	0.017	0.258	0.357	0.001	0.800	0.120	0.001	0.591	0.023

[a–e]Within a column, means without a common superscript differ ($P < 0.05$).

[1]Feed conversion ratio.

[2]Standard deviation: n = 30 replicates for feed form and n = 12 replicates for AME_n content of the diet.

Table 10. Influence of feed form and energy content (AME_n, kcal/kg) of the diet on energy intake[1] (kcal AME_n/d) and energy efficiency (kcal AME_n/g) of the pullets from hatching to 5 wk age, Experiment 2.

Feed form	AME_n (kcal/kg)	0 to 5 wk	
		EnI	EnE
Mash	2,850	60.5[c]	6.65[bc]
	2,900	62.5[abc]	6.74[ab]
	2,950	64.1[ab]	7.03[a]
	3,000	64.7[ab]	6.94[a]
	3,050	65.7[a]	7.02[a]
Crumbles	2,850	61.9[bc]	6.32[c]
	2,900	62.0[bc]	6.28[c]
	2,950	62.3[abc]	6.41[bc]
	3,000	62.3[abc]	6.30[c]
	3,050	62.4[abc]	6.29[c]
Standard deviation[2]		1.71	0.208
Probability			
Feed form		0.005	<.001
AME_n			
Linear		<.001	<.001
Quadratic		0.337	0.201
Feed form ×AME_n		0.001	0.013

[a–c]Within a column, means without a common superscript differ ($P < 0.05$).

[1]Calculated energy intake (kcal AME_n/d). Calculated AME_n values of the diets are presented in Table 4.

[2]Standard deviation: n = 30 replicates for feed form and n = 12 replicates for AME_n content of the diet.

as compared with broilers fed a control diet. Similarly, González-Alvarado et al. (2007) reported that the inclusion of 3% OH or 3% soy hulls in the diet of broilers from 1 to 21 d age improved ADG by 5.4% for both fiber sources, and FCR by 2.9 and 2.2%, respectively. However, FI was not affected by fiber inclusion in any of these studies conducted with broilers, whereas a significant increase of 3.6% was detected in the current study conducted with pullets.

The inclusion of fiber in the diet improved EnE within the range of 0.9% (4% SBP-containing diet) and 4.4% (2% SFH-containing diet) as compared with the control diet. González-Alvarado et al. (2010) reported a 5.8% increase in EnE with 3% OH inclusion in broilers from 1 to 42 d age, and Jiménez-Moreno et al. (2013) showed a 4.3% improvement in EnE in broilers fed diets with 5.0% SBP from 1 to 18 d age as compared with broilers fed the control diet. The data also suggest that during the initial stages of the rearing period, pullets might benefit from the inclusion of moderate amounts of fiber in the diet but that the benefits on ADG and EnE might be less pronounced in pullets than in broilers. Broilers had a higher capacity for FI and grew faster than pullets. Also, fiber content is lower in commercial diets for broilers than in commercial diets for pullets. Consequently, under practical conditions, additional dietary fiber might be more beneficial in young broilers than in young pullets.

From hatching to 5 wk age pullets fed SFH grew as an average 2.8% faster than pullets fed SBP, with pullets fed straw being intermediate. Jiménez-Moreno et al. (2010) also observed that broilers fed 3% OH, an insoluble fiber source, grew 6.3% faster from 1 to 21 d age than broilers fed 3% SBP, a soluble fiber source. Similarly, González-Alvarado et al. (2010) reported 7.1% higher ADG in broilers fed 3% OH than in broilers fed 3% SBP from 1 to 42 d age. The differences in ADG observed between birds fed SFH and SBP might be related to differences in the physico-chemical characteristics of the 2 fiber sources. For example, pectin content is higher in SBP than in SFH; pectins increase water retention and volume and viscosity of the digesta in the GIT, which may lead to faster satiety and less growth of the birds.

Pullets fed diets with 4% added fiber were less efficient than pullets fed diets with 2% added fiber. Jiménez-Moreno et al. (2013) reported also a reduction in feed efficiency in broilers from 1 to 18 d age as the level of OH or SBP in the diet increased from 2.5 to 7.5%. Similarly, Pettersson and Razdan (1993)

Table 11. Influence of feed form and energy content (AME_n, kcal/kg) of the diet on BW uniformity[1] of the pullets, Experiment 2.

	Hatching	1 wk	2 wk	3 wk	4 wk	5 wk
Feed form						
Mash	7.67	9.96	9.77	10.19[a]	8.76[a]	8.50
Crumbles	7.79	9.24	9.35	8.81[b]	8.01[b]	7.97
AME_n (kcal/kg)						
2,850	7.58	8.86	9.47	10.61	8.45	8.55
2,900	7.67	9.47	9.09	8.71	9.00	7.99
2,950	7.81	9.82	9.61	9.40	7.77	8.18
3,000	7.63	10.01	9.45	9.08	8.00	8.03
3,050	7.96	9.84	10.18	9.72	8.69	8.42
Standard deviation[2]	0.841	1.597	1.184	2.286	1.386	1.155
			Probability			
Feed form	0.572	0.089	0.175	0.023	0.042	0.077
AME_n						
Linear	0.360	0.094	0.101	0.515	0.694	0.827
Quadratic	0.877	0.324	0.236	0.103	0.266	0.215
Feed form ×AME_n	0.738	0.856	0.105	0.092	0.628	0.989

[1]Evaluated as the CV (%) of BW (Peak et al., 2000).

[2]Standard deviation: n = 30 replicates for feed form and n = 12 replicates for AME_n content of the diet.

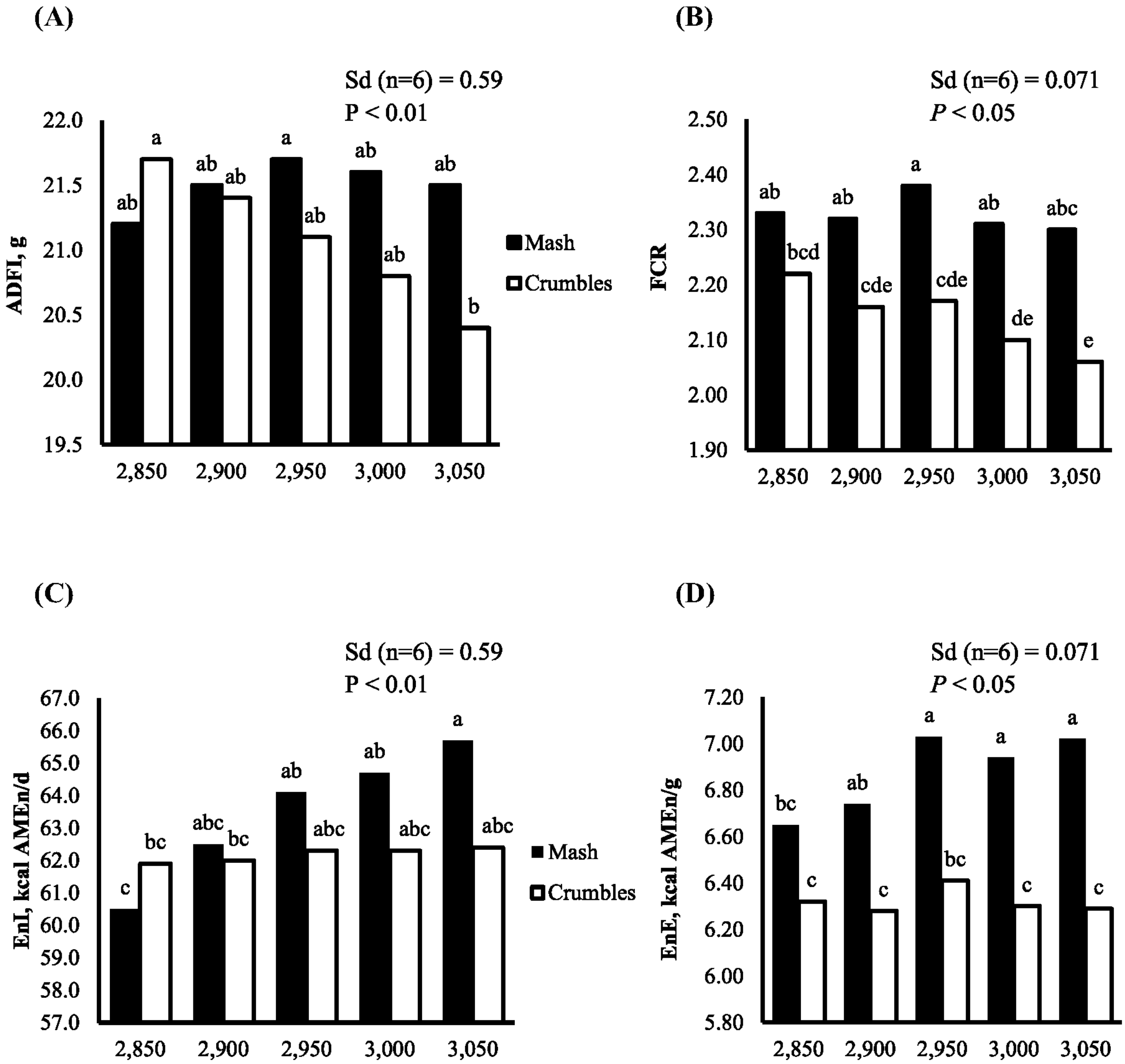

Figure 1. Interaction between feed form and energy content (AME_n, kcal/kg) of the diet on (A) ADFI, (B) FCR, (C) energy intake, and (D) energy efficiency from hatching to 5 wk age, Experiment 2.

showed a reduction in feed efficiency in broilers from 1 to 21 d age when the SBP of the diet was increased from 2.3 to 4.6% or 9.2%. The data suggest that similar to what have been observed in broilers, young pullets might benefit when additional fiber sources are included in low-fiber diets but that an excess of fiber might not be of benefit. Possibly, pullets might require a minimum of 3.2 to 3.5% crude fiber (equivalent to 9.2 to 9.5% NDF, approximately) to maximize growth performance from hatching to 5 wk age. In this respect, Fundación Española Desarrollo Nutrición Animal (2008) recommended at least 3.0% CF in this period. However, neither the National Research Council (1994) nor the main companies involved in poultry genetics (e.g., Hy-Line International, 2013; Lohmann, 2013) have made any suggestions on the most convenient level of fiber in diets for young pullets.

Body weight uniformity was not affected by the inclusion of fiber in the diet. The authors have not found any published report on the influence of fiber inclusion in the diet on this trait. The data indicate that when moderate amounts of fiber are included in the diet, BW uniformity will not be affected.

Experiment 2

Feed form. The GMD of the mash diets was not affected by energy concentration of the feed but that of the crumble diets decreased as the AME_n increased. The high-energy diets contained more fat than the low-energy diets, and an increase in fat content might reduce crumble quality, increasing the percentage of fines (Briggs et al., 1999). In contrast, dust formation is reduced in mash diets when the level of fat is increased and therefore no reduction in GMD should be expected.

Numerous studies have reported that crumbling or pelleting of the diets improves performance in broilers (Amerah et al., 2007; Brickett et al., 2007; Serrano et al., 2012) and pullets (Frikha et al., 2009b). The heat and pressure applied during the pelleting process reduces further the particle size of some of the ingredients of the feed, fracturing the endosperm and disrupting the outer coat of the seeds (Svihus et al., 2004; Amerah et al., 2007). Consequently, pelleting facilitates the release of the intracellular oil contained in the ingredients, as well as the access of digestive enzymes to nutrients. Also, the heat applied during the pelleting process might modify at some extent the structure of the protein fraction, reducing the activity of some antinutritional factors present in plant ingredients and increasing CP digestibility (Herkelman et al., 1991). In addition, pellets might reduce the energy spent by the bird in feed ingestion, which may decrease further energy requirements (Abdollahi et al., 2012). From hatching to 5 wk age, pullets fed crumbles had 6.5% higher ADG and 8.2% better FCR than pullets fed mash. These results agree with data of Frikha et al. (2009b) who reported in 45-day-old pullets a 5.9% improvement in ADG when fed pellets, although in this study FCR was not affected.

For the first week of age, FI was greater in pullets fed crumbles than in pullets fed mash but the opposite results were observed after this age. In contrast, ADG and FCR were better for pullets fed crumbles at all ages. The reason for the lower FI with mash feeding during the first week of life is not known. Mash feeding increases the time and energy spent by the chick in the apprehension of the feed (Jensen et al., 1962; Savory, 1974), and therefore very young chicks, that have a limited GIT capacity, might not be able of consuming enough feed to optimize performance. In this respect, pullets were beak-trimmed immediately after hatching which might have reduced FI early in life in birds fed mash. Also, the size of the crumbles used might have been bigger than required for very young pullets and might not have fit well in the beak of the bird, resulting in an increase in feed wastage (Workman and Rogers, 1990). After the first week of life, however, GIT development and capacity might be sufficient to meet the energy needs of the pullets. Moreover, crumbling might reduce feed wastage as has been reported in broilers by Mateos et al. (2002) and Serrano et al. (2013). GIT capacity and feed wastage, however, were not measured in this study and therefore this hypothesis needs further testing.

At 5 wk age, pullets fed crumbles tended to have better BW uniformity than pullets fed mash, consistent with data of Brickett et al. (2007) in 5-week-old broilers. In contrast, Frikha et al. (2009b) did not find any difference in BW uniformity of 45-day-old pullets fed mash or 2 mm pellet diets. The discrepancies reported on BW uniformity of the birds among these studies suggest that other factors, such as type and age of the birds, and method used for beak-trimming, as well as the ingredient composition of the diet, might affect the response to feed form.

Energy concentration. Poultry eats to satisfy their energy requirements and therefore ADFI should decrease and FCR should improve with increases in the energy density of the diet. In this study, however, pullets fed mash tended to overconsume energy as the AME_n of the diet increased, whereas pullets fed crumbles were able of adjusting their EnI. Consequently, EnE was not affected by energy concentration of the diet in pullets fed crumbles but was hindered in pullets fed mash. The authors have not found any published research in pullets on the potential interaction between the energy content of the diet and feed form to compare with the results reported in this paper. The data suggest that pullets fed mash were either unable to regulate feed consumption to fit energy requirements or wasted more feed than pullets fed crumbles. Consequently, an increase in the energy content of the diet resulted in an EnI that was higher than the real consumption. The greater feed wastage that possibly occurred when pullets were fed mash as compared with pullets fed crumbles might explain the absence of effects of an increase in the energy concentration of the diet on reducing the ADFI and improving the FCR in these birds.

The distinct effect of energy concentration of the diet on FI in pullets fed mash or crumble diets are of considerable practical interest. The data reported in this paper suggest that young pullets have a greater ability to regulate ADFI when fed a pellet diet than when fed a mash diet that is possibly less palatable, as has been shown in broilers by Scott (2002) and Brickett et al. (2007). In fact, Brickett et al. (2007) observed that broilers regulate better voluntary FI of diets varying in energy concentration when fed pellets than when fed mash.

Body weight uniformity was not affected by energy concentration of the diet at any age, in agreement with data of Frikha et al. (2009a) in 45-day-old brown-egg pullets fed diets varying in AME_n content from 2,735 to 3,025 kcal/kg. Also, Brickett et al. (2007) reported in 35-day-old broilers that BW uniformity was not affected by the energy concentration of the diet. However, Keshavarz (1998) observed a significant improvement in BW uniformity of 18-week-old pullets when the AME_n of the mash diet was increased from 2,815 to 3,035 kcal/kg. The reason for the discrepancies reported among different studies is unknown although factors such as type and age of the birds, flock management, including rearing density, and the characteristics of the experimental diets, might affect the outcome of the study.

In summary, the inclusion of 2% fiber source in a corn-wheat-soybean meal diet improved pullet performance from hatching to 5 wk age, an effect that tended to be more pronounced with SFH than with straw or SBP inclusion. An increase in the level of fiber from 2 to 4% reduced growth performance, especially when SBP was used. Feeding crumbles to pullets improved ADG and FCR, and tended to improve BW uniformity as compared with feeding mash. An increase in the energy content of the diet decreased ADFI in pullets fed crumbles but no effects were detected in pullets fed mash. Neither ADG nor BW uniformity were affected by the energy content of the diet. The results indicate that from hatching to 5 wk age, pullets might require a minimal amount of dietary fiber to maximize growth performance. Moreover, at this early stage of the rearing period crumbled feeds might be preferred to mash feeds. The beneficial effect of increasing the energy content of the diet on pullet performance might depend on the feed form and on the relative cost of available ingredients.

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